A TEMPLATE FOR OPEN INQUIRY

Using questions to encourage and support inquiry in Earth and space science

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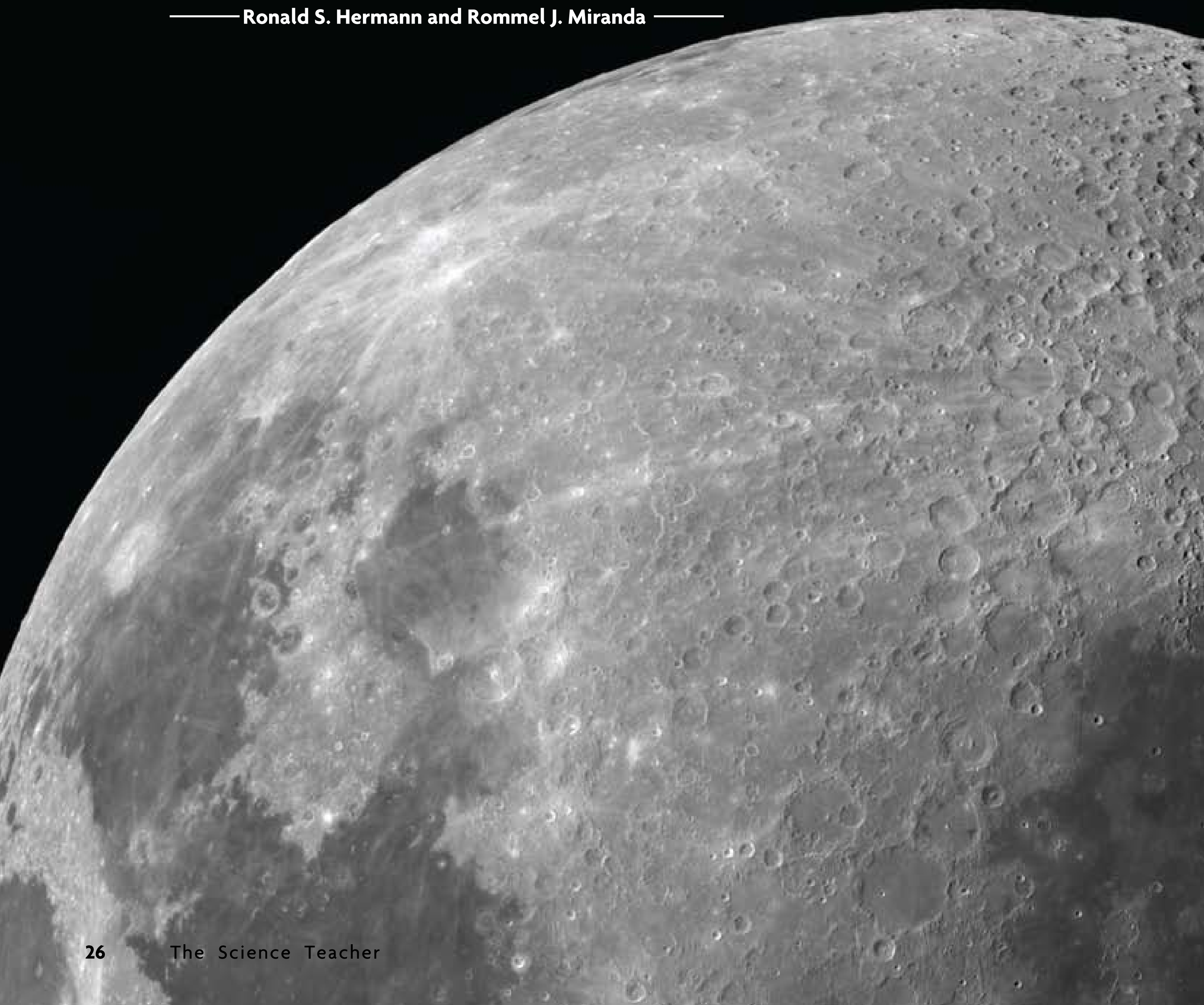

Over the past few decades, much has been written about what inquiry is and is not. Inquiry should not be considered a singular construct, but rather a range of approaches that form a continuum. The National Research Council provides one example; this continuum ranges from more to less learner self-direction with respect to five features of inquiry (Figure 1, p. 28; NRC 2000).

Although inquiry can be described this way, some researchers have found it helpful to demarcate the continuum with descriptive stages—and differentiate whether the instructor or the learner is responsible for developing specified learning outcomes. For example,

- in *confirmation,* students are provided with a question, and the results are known in advance;
- in *structured inquiry,* the question and procedure are provided, but students generate an explanation supported by their collected evidence;
- in *guided inquiry,* the teacher provides the question, but students design the procedures and develop explanations; and
- in *open inquiry,* students develop questions and procedures, carry out experiments, and communicate their results (Bell, Smetana, and Binns 2005).

Although inquiry-based instruction has been written about for decades, there is little evidence that it is widely used in science classrooms. Open inquiry, in particular, is often thought to be difficult to use in the classroom, and Settlage (2007) has argued that it is impractical for teachers to regularly implement. Perhaps one explanation for this is the perceived difficulty in moving students toward the development of novel research questions.

This article provides an instructional approach to helping students generate open-inquiry research questions, which we call the *open-inquiry question template.* This template (Figure 2, p. 29) was created based on our experience teaching high school science and preservice university methods courses. To help teachers implement this template, we describe its use in a ninth-grade Earth and space science class, in which students learn about meteorite impacts. The lesson takes place over two, 90-minute class periods.

The instructional approach

The open-inquiry template is designed to facilitate student-generated research questions by providing a highly structured yet open-ended questioning format (Figure 2). We have found that when moving students toward the open-inquiry end of the continuum, using a control-group experimental research design—in which only one variable is changed to determine the effect upon another variable—helps limit frustration for students and teachers alike. In these types of experiments, there are independent and dependent variables that are quantifiable and controlled for confounding variables. This type of design provides a strong foundation upon which students can build understanding of less tangible scientific skills and processes.

Once students understand the process by which meaningful and context-driven research questions are developed, they are more capable of developing open-ended research questions.

The Earth and space lesson

To begin the lesson on impact craters, we use an internet browser to find images and create a PowerPoint presentation with pictures of the Moon in various phases, impact craters, and the Moon as it typically appears from Earth with the naked eye. (**Note:** Check website copyright laws and requirements before using images in class.) We then show this slideshow to students on an LCD projector and ask them, as a class, to compile a list of observations (question 1, Figure 2).

Inevitably, students observe that the Moon appears to go through phases and that the surface appears dust-like and heavily cratered. They are then asked to select an observable quality of the Moon that they wish to explore further. Although the list of observable qualities is often long, the phases of the Moon, the position of the Moon in the sky, or the differences in crater size and shape are common choices.

The template described in this article is appropriate for any of these explorations. However, to illustrate the template most effectively, we describe how students have used it to arrive at open-inquiry questions about impact craters on the Moon.

FIGURE 1

Inquiry continuum (NRC 2000).

Essential features of classroom inquiry and their variations.

	Essential feature	Variations			
1	Learner engages in scientifically oriented questions.	Learner poses a question.	Learner selects among questions, poses new questions.	Learner sharpens or clarifies question provided by teacher, materials, or other source.	Learner engages in question provided by teacher, materials, or other source.
2	Learner gives priority to evidence in responding to questions.	Learner determines what constitutes evidence and collects it.	Learner is directed to collect certain data.	Learner is given data and asked to analyze.	Learner is given data and told how to analyze.
3	Learner formulates explanations from evidence.	Learner formulates explanation after summarizing evidence.	Learner is guided in process of formulating explanations from evidence.	Learner is given possible ways to use evidence to formulate explanation.	Learner is provided with evidence.
4	Learner connects explanations to scientific knowledge.	Learner independently examines other resources and forms the links to explanations.	Learner is directed toward areas and sources of scientific knowledge.	Learner is given possible connections.	
5	Learner communicates and justifies explanations.	Learner forms reasonable and logical argument to communicate explanations.	Learner is coached in development of communication.	Learner is provided broad guidelines to sharpen communication.	Learner is given steps and procedures for communication.

More <--------------- Amount of learner self-direction ---------------> Less

Less <----------- Amount of direction from teacher or material -----------> More

Observable variables

Once students key in on variations in the Moon's craters, they are asked to generate a list of observable characteristics (question 2, Figure 2). This list typically includes such observations as the size and shape of the craters, their depth, the differences in shadow intensity found within them, and the position and extent of ejected fragments. This is a great time to introduce the difference between observation and inference. For example, students might *observe* that the diameters of craters vary and *infer* that this is due to meteorites of different diameters, speeds, and masses crashing into the Moon. Students then share their responses with the class.

At this point, students often do not realize that they have generated a list of variables. The next step is to call their attention to this, starting with the independent variables. One way to help students conceptualize this is to explain that exact information about these variables can be known prior to the experiment. For example, in an experiment on the relationship between the slope of an inclined plane and the distance a steel ball will travel, the various slope angles that will be tested are known in advance (the independent variable), but the distance the steel ball will actually travel is not.

Independent variables

Students then develop a list of independent variables that are observable and quantifiable and could conceivably result in the formation of a meteorite crater (question 3, Figure 2). Students may note that some of the independent variables have already been stated in the previous question. However, this time around, they are only focusing on the independent variables. Common independent variables might include the speed, size, mass, and shape of a meteorite; the type and amount of material impacted; or the angle at which the material is impacted.

Once their list is generated, students then consider how they can measure the variables they have selected (question 4, Figure 2). This ensures the quantitative nature of the study. For example, students might decide to use spheres of different sizes and measure their diameter in millimeters. As teachers, we must ensure that students reduce confounding variables by providing experimental controls. In this example, that would mean ensuring the spheres all have the same mass and vary only in their diameter. However, this step comes later on, and teachers should refrain from engaging in such discussions at this early stage of research-question development.

Students should consider their list of independent variables as a brainstorming exercise and not become too attached to any particular variable. Once again, students share their responses with the class.

Dependent variables

The next question on the template facilitates the development of quantifiable dependent variables. Here, students are asked to list factors that may change based on some of the independent variables (question 5, Figure 2); these might include the size, depth, and shape of the crater; the distance ejected material moves after the impact; or the direction of ejected material. Students may again note that some of these variables were listed in the first brainstorming question, but here they are thinking only of those that occur as a result of a change in the independent variable.

After developing this list, students again construct a list of measurements that can be made to quantify the changes that have occurred (question 6, Figure 2). For example, students can measure the crater diameter in millimeters. As teachers, we may be tempted to ensure that students duplicate their measurements accurately, but this too comes later in the activity.

At this point, it is helpful to engage students in a discussion about materials that can be used to simulate the experimental conditions they have been discussing (question 7, Figure 2). In this case, students often mention using sand or flour to simulate the Moon's surface and dropping rocks or different-size balls (e.g., golf balls, baseballs) to simulate meteorites of different sizes or mass.

The research question

Students have now constructed extensive lists of both independent and dependent variables as a class. These lists provide a wealth of variables to draw from when constructing their research questions in collaborative groups (question 8, Figure 2). This helps minimize the frustration that may result when students are asked to develop a research question without any guidance. It also helps teachers who are used to a structured environment move toward implementing open-inquiry experiences.

FIGURE 2

Open-inquiry question template.

Prelab questions

1. List observations and inferences that can be made from the images you are shown.
2. Given the observations and inferences you listed, what characteristics (variables) can be identified and what kinds of measurements can be made?
3. What variable(s) can you change (i.e., independent variable)?
4. How can you measure (quantify) the independent variable? Include units of measurement, if known.
5. What variable(s) could be affected by the changes made (i.e., dependent variables)?
6. How can you measure the dependent variable? Include units of measurement, if known.
7. In light of the phenomenon being studied, what materials can be used to simulate the conditions necessary to run an experiment?

Research question

8. Based on the variables identified in the prelab, write a question that you can test using the materials identified. Include the independent and dependent variables.

The experiment

9. Describe an experimental approach to determining the effect that changing the independent variable has on the dependent variable. Write the steps you will follow in conducting your experiment. (**Note:** A classmate should be able to reproduce these steps.)
10. Gather the materials needed and conduct the experiment you designed.
11. Make a data table that shows the results of your experiment.
12. Make a graph of your data that represents the relationship between the variables.
13. Based on the results of your experiment, what is the relationship between the independent and dependent variables?
14. What conclusions can you make about the interaction of the two variables you tested in a natural setting?
15. Were there any sources of error that influenced your results? If so, what were they, and how can they be minimized?

The lists of variables tend to result in an assortment of potential student research questions. For example, a student might explore the relationship between the speed at which a sphere hits the Moon's surface and the depth of the crater it creates. In some cases, we have encouraged students to develop novel research questions by requiring groups with the same question to discard it and select a new one.

The experiment

Once students have constructed their research questions, they are ready to begin conducting their experiments. The remaining template questions guide students through the development of an appropriate experimental design. First, students make a list of the materials they will need to conduct their experiment. This way, the teacher can acquire the materials before the next class. Otherwise, the teacher can anticipate the materials that might be needed by trying to account for the types of variables students are likely to develop (Hermann and Miranda 2010). By collecting students' methods section prior to the experiment and reviewing the needed materials, teachers can ensure that all classroom and laboratory safety guidelines are followed.

Next, students develop the steps for their experiments to ensure that they can be replicated by themselves and others (question 9, Figure 2, p. 29). This can be completed as a homework assignment or in class and mirrors the experience of scientists—as students often have to engineer a device to help them conduct the experiment. For example, students who want to measure the speed of a sphere prior to impact have to determine a way to do this, given the materials at their disposal. They may have to settle for simply dropping the spheres from different heights and not knowing the exact speed (though some schools may have motion-sensing probeware capable of accurately measuring the speed of falling projectiles).

Prior to conducting the experiment, teachers will want to meet with students to discuss their experimental designs. Teachers can ask probing questions to help students determine whether they have addressed all confounding variables, or they can let students complete the experiment as designed, even if there are design flaws, and discuss the confounding variables (question 15, Figure 2) later in the lesson. We have also had great success requiring groups to exchange methods with another group for peer review prior to conducting the experiment.

The teacher's discussion with the group provides an opportunity to ensure that students are following all safety guidelines. After meeting with the teacher, students should gather the materials needed for their experiments (question 10, Figure 2).

While students are conducting their experiments, they are expected to construct a data table (question 11, Figure 2) and a graph (question 12, Figure 2) to represent their data. The teacher facilitates this process by asking probing questions about students' data and how the variables relate to one another—but the teacher must resist the temptation to tell students how to set up the table and graph. As a result, students begin to develop the skills necessary to determine whether their findings are within the realm of acceptable solutions to their problem. In other words, how well do their results answer the research question? Do their results seem appropriate? Students may learn just as much, if not more, by identifying errors in their experiment rather than finding the "correct" answer.

Finally, students should be encouraged to discuss how well their experiment models what one would expect to observe in a natural setting (in this case, on the Moon) (questions 13–15, Figure 2).

Conclusion

Inquiry-based activities closely resemble the skills and processes of science undertaken by scientists and incorporate the nature of science in more meaningful ways than traditional, cookbook-type labs. However, teachers can easily become frustrated with students' inability to formulate and carry out their own research. The open-inquiry question template presented in this article is one example of a structured approach to open inquiry that typically results in a rich and satisfying research experience for both students and teachers. ■

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Author's note

Thanks to an insightful reviewer of this manuscript, we learned of an approach reported by Cothron, Giese, and Rezba (2006) that is similar to ours. Readers should further consult this source for a detailed report of the *4-Question Strategy.*

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